KENYA POWER SECTOR DEVELOPNET SCENARIOS – ANALYSIS USING LONG RANGE ENERGY ALTERNATIVE PLANNING SYSTEM

***D. W. Irungu*[1], *S. N. Kahiu*[2], *S . M . Maranga*[1] *and J. N. Kamau*[3]**
[1]Department of Mechanical Engineering, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya
[2]Institute of Energy and Environmental Technology, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya
[3]Department of Physics, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya
E-mail: dirungu@jkuat.ac.ke

Abstract
Energy is universally recognized as one of the most fundamental inputs for social and economic development. Currently, the estimated access to electricity in Kenya stands at 63%. The Government has a plan to increase this accessibility to 100% and achieve 100% connectivity by 2030 through implementation of the Least Cost Power Development Plan (LCPDP), extension of the grid and establishment of mini-grids in areas where extension of grid is not economically feasible. This paper seeks to analyze three possible power development scenarios in relation to their Green House Gas (GHG) emissions and cost implications. The LCPDP forms the reference scenario, it has a supply mix of hydro, geothermal, thermal (including Gas turbine and Medium Speed Diesel Plants), nuclear, wind and coal power plants. The second scenario has a supply mix of hydro, geothermal, thermal (Gas Turbine Plants only), nuclear, wind and coal power plants. The third scenario will have a supply mix of hydro, geothermal, thermal (Gas Turbine Plants), nuclear, wind, coal power plants and 5% small renewable (small-hydro, solar-PV and biomass plants) as non-dispatchable plants. The expansion plan is modeled from 2012 -2030 using the Long Range Energy Alternative Planning System (LEAP). The demand forecast for the domestic, industrial, commercial and street lighting sectors is carried out to simulate how the power demand is expected to change from an estimated peak demand of 1300MW to 7500MW in 2030. The results from the reference scenario show that it's the most economically viable option of generating power but with the highest carbon footprint. The second scenario if implemented would lead to a GHG saving of 2.2million tonnes of CO_2 equivalent, at a cost of $45.6/tonne CO_2 eq. The third scenario would lead to a GHG saving of 6.2million tonnes of CO_2eq, at a cost of $8.6/tonne CO_2eq. Therefore third scenario has the greatest saving in terms of the GHG emissions and would be the ideal path for Kenya to follow in terms of energy security and mitigation of the adverse effects brought about by climate change.

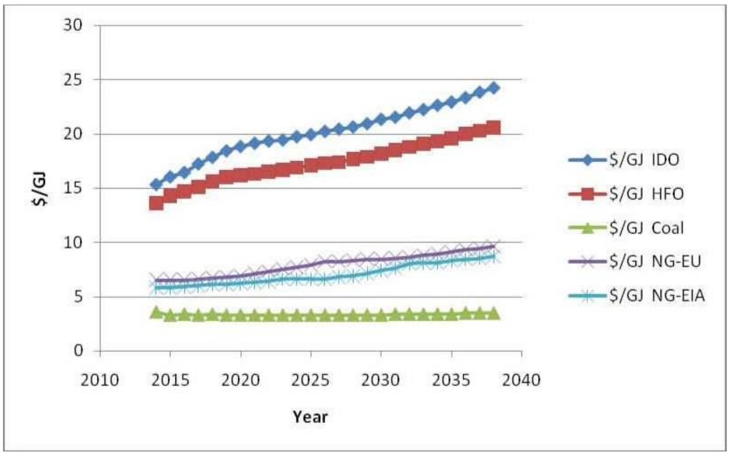
Key words: Kenya, energy scenarios, greenhouse gas emissions

1.0 Introduction

Energy has been universally recognized as one of the key elements for development. In order for a country to achieve high economic growth rates, there has to be adequate power supply, as shown by (Ferguson *et al*., 2000) in their study of electricity use and economic growth for one hundred countries. Kenya aspires to be a middle income economy by 2030 with a robust manufacturing sector which will be driven by adequate, reliable and affordable power supply. Currently it is classified as a low income developing country by the World Bank. It has a power generation capacity of 1,690MW (Kenya Power, 2012) with a supply mix comprising of hydro, thermal, geothermal, wind and cogeneration plants. The power supply rate to its population is 18% with connections in the upper and middle income groups (Kiplagat *et al*., 2011; ERC, 2011). The consumption per capita is estimated to be 156kWh (IEA, 2012).

To address the challanges in the power sector of low connection rates, power supply and demand imbalance as well as enhance efficiency, major reforms have been undertaken in the recent past. These include; liberalization of the power generation, unbundling of the state power utility company as per the recommendation of the sessional paper four on energy (MOE, 2004) and enactment of the energy Act of 2006. There is also the development of a power expansion plan to ensure that, there is sufficient power to satify the projected demand from all sectors of the economy, with a reserve margin of 25% and at the least cost. This plan is based on the Wien Automatic System Planning Package (WASP) model, whose output is the optimal Least Cost Power Development Plan (LCPDP) for various demand scenarios; low, reference and high. Through the plan the generation capacity is expected to grow from the current 1690MW to 20,156MW by 2030 in the reference scenario. The supply mix is expected to comprise of 26% Geothermal, 19% Nuclear, 13% Coal, 9% imports from the East African Power Pool(EAPP), 9% Wind, 5% Hydro, 9% Medium Speed Diesel(MSD) and 11% Gas Turbine (ERC, 2011). However, it does not include power generation scenarios based on anticipated policy changes.

This study attempts to analyse other possible power development scenarios that could arise due to a change in policy and compares them with the least cost plan in-terms of emissions and the cost implications using the Long Range Energy Alternative Planning System(LEAP) modeling software. The three scenarios to be assessed includes; Reference Scenario (RS) which represents the implementation of the least cost plan with no changes in policy, the second scenario which is Natural Gas Scenario (NGS), informed by a policy which blocks the building of new Medium Speed Diesel (MSD) plants after 2013, due to the high costs of fuels i.e. Industrial Diesel Oil (IDO) and Heavy Fuel Oil (HFO) as compared to natural gas as shown in Figure1. The third is the Renewable Scenario.



Source: (SNC Lavalin International INC. and Parsons Brinckerhoff, 2011)

Figure 1: Fuel forecast

(RES) which ensures that the small scale renewable plant are integrated into the grid to supply at least 5% of the total power by 2030. This aims to ensure sustainability of the power supply and cushion the consumers from the fluctuating cost of fuel passed to them directly as per the tariff structure through the Fuel Oil Cost Adjustment(FOCA). The RES is informed by the technical and economic study for development of small scale grid connected renewable energy in Kenya (ECA, 2012).

Their analysis of small renewable energy projects, indicated that these small renewable energy contribute 350MW in 2018 which will be 6% of the generation capacity. In this research, LEAP is used to characterise the composition and structure of electricity, fuel use and GHG emissions for each scenario.

2.0 Literature Review

Various researchers have undertaken scenario analysis for power sectors in different coun- tries. Scenario planning is a useful approach to design and plan for long term electricity infrastructures to cope with uncertain future demand for power (Y.Mulugetta *et al.,* 2007). It allows the construction of a repertoire of possibilities that are linked to a variety of pol- icy and technical pathways which capture effectively the uncertainities that lie ahead in the energy, economic and environmental domains (Craig *et al.*, 2002). In energy research, these long-time scenarios usually consist of different storylines that offer a set of alterna- tive contexts for exploring the different ways that the future may unfold (Ghanadan and Koomey, 2005).

(Y.Mulugetta *et al.,* 2007) did an analysis of Thailand power sector using three scenarios; the ‘Business As Usual Scenario’(BAU) where fossil fuels would continue to dominate elec- tricity generation, the ‘No

New Coal scenario'(NNC) where dependence on on coal and oil shifted towards natural gas-based power generation, and finally the 'Green Future scenario' (GF) where 35% of the capacity is derived from renewable energy sources.

(Dagher and Ruble, 2011) modeled possible future paths for Lebanon's electricity and performed a fully- fledged scenario analysis to examine the technical, economic and envi- ronmental implications of all scenarios. These were; the 'Baseline Scenario' which described the business-as-usual state of affairs capturing the most likely evolution of the power sec- tor in the absence of any climate change related or other policies, the ' Renewable Energy Scenario'(RES) incorporated specific policies aimed at expanding renewable energy's share and reducing GHG emissions, the ' Natural Gas Scenario'(NGS) assumed that the growth in electricity demand was met by introduction and expansion of natural gas combined cycle generators along with an expansion of the existing technology. (Özer *et al.,* 2013) used two scenarios; Business as usual scenario and mitigation scenario to model different development paths that are possible for Turkey electricity sector. (H.Gujba *et al.,* 2011) developed four scenarios which included two fossil fuel(FF and CCGT) and two sustainable development scenario(SD1 and SD2) and compared them with the Government power expansion plan interms of cost and environmental impacts for short to medium term.

In Kenya no study has been done as yet, to compare various possible generation pathways that can be brought about by change in policy. This study models different generation path- ways and compares them to the least cost plan in terms of costs and emissions. Overview of the scenarios used in this study is given in the Table 1 and 2.

Table 1: Overview of the alternative scenario assumption

Overview of the alternative Scenario assumptions

	Reference Scenario	**Natural Gas Scenario**	**Renewable Scenario**
Driving philosophy	This represents the least cost power development plan being implemented as it is with no anticipated changes in policy	Inspired by the cost of natural gas prices being lower than those of (HFO) and (IDO). Natural Gas emissions being less than those of fuel oil.	Inspired by the uncertainty of the fossil fuel prices to cushion the consumers from the high electricity bills
Demand	Growth of demand in Domestic, Small Commercial, Street lighting, and Commercial and Industrial sector follows Load Forecast Report 2012 Number of households is determined from the population data with projection done using KNBS growth rates of 2.5% up to 2020 then 2.2% to 2030. The share of urban population is expected to be 61% by 2030 <u>Final Energy Intensity</u> Urban household: The average annual growth rate of energy consumption per household is 1.00% from 2012 to 2030 Rural household: The average annual growth rate of energy consumption per household is 1.01% from 2012 t0 2030 Commercial & Industrial: The average annual growth rate of energy consumption is 2% from 2012 to 2030 Street lighting: The average annual growth rate of energy consumption is 1.2% from 2012 to 2030		
Supply side	System load factor = 68%	System load factor = 68%	System load factor = 68%
	Committed Project(Exogenous Capacity) and Retirements		
	Upgrading of Hydro plant (Kindaruma) to gain 32MW in 2014	Upgrading of Hydro plant (Kindaruma) to gain 32MW in 2014	Upgrading of Hydro plant (Kindaruma) to gain 32MW
	Upgrading of Geothermal Plants in 2014, 36MW, and Well head Generator 35MW, 2015, 140MW.	Upgrading of Geothermal Plants in 2014, 36MW, and Well head Generator 35MW, 2015, 140MW.	Upgrading of Geothermal Plants in 2014, 36MW, and Well head Generator 35MW, 2015, 140MW.
	New Coal Plants 2015 20MW	New Coal Plants 2015 20MW	New Coal Plants 2015 20MW
	New MSD plants 2013, 332MW	New MSD plants 2013, 332MW	New MSD plants 2013, 332MW

Table 2: Overview of the alternative scenario assumption

	Reference Scenario	Natural Gas Scenario	Renewable Scenario
Supply Side	Decommission Thermal MSD Plants 2019, 56MW, 2021, 74MW, 2023, 75MW	Decommission Thermal MSD Plants 2019, 56MW, 2021, 74MW, 2023, 75MW	Decommission Thermal MSD Plants 2019, 56MW, 2021, 74MW, 2023, 75MW
	Decommission Gas Turbine Plants 2014, 60MW	Decommission Gas Turbine Plants 2014, 60MW	Decommission Gas Turbine Plants 2014, 60MW
	Decommission Geothermal Plants 2028, 52MW, 2029, 70MW	Decommission Geothermal Plants 2028, 52MW, 2029, 70MW	Decommission Geothermal Plants 2028, 52MW, 2029, 70MW
	Decommission Cogeneration 2019, 26MW	Decommission Cogeneration 2019, 26MW	Decommission Cogeneration 2019, 26MW
	Endogenous Capacity (Candidate Plants)		
	Geothermal Plants 140MW	Geothermal Plants 140MW	Small renewable Plants to form 5% of total generation capacity.(Small Hydro, Biomass, Solar)
	Coal Plants 300MW	Coal Plants 300MW	Geothermal Plants 140MW
	Hydro Imports 200MW	Hydro Imports 200MW	Coal Plants 300MW
	MSD Plants 160MW	Wind 300MW	Hydro Imports 200MW
	Wind 300MW	Natural Gas 180MW	Wind 300MW
	Natural Gas 180MW	Nuclear 1000MW	Natural Gas 180MW
	Nuclear 1000MW		Nuclear 1000MW

3.0 Methodology
In order to evaluate different scenarios of how the future energy system might evolve over time in a particular demographic, socio-economic setting and under particular set of policy conditions, the following analyses were performed; demand, transformation/power supply, and environmental analysis.

3.1 Final Energy Demand Analysis
The final energy demand was determined according to consumer categories. The categories included; street lighting, Industrial, domestic, small commercial, medium Commercial and large Commercial consumers.

The domestic load forecast was based on the load forecasting report (Texier et al., 2012).The activity level choosen for domestic consumer analysis was the household which were clas- sified as per the Kenya Power regions i.e. Nairobi, Western Kenya, Mt. Kenya and Coast regions as shown in the Figure: 2. The households were further categorised based on location and income levels.

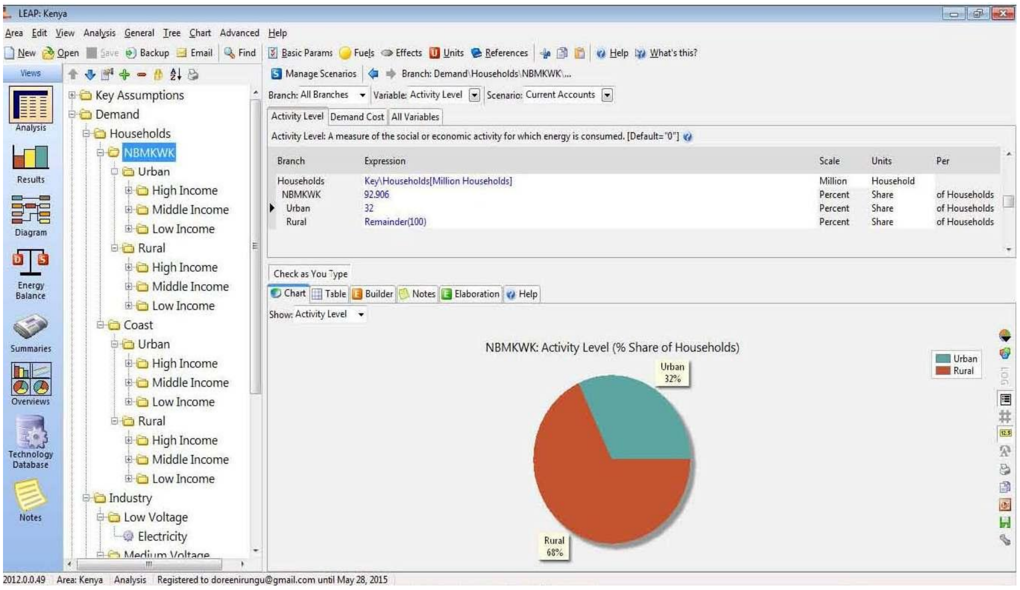


Figure 2: Households as captured in LEAP

Under the different income levels, the specific consumption of fifteen clustered appliances (kWh/year) and the levels of penetrations were used to determine the domestic demand as shown in Figure 3.

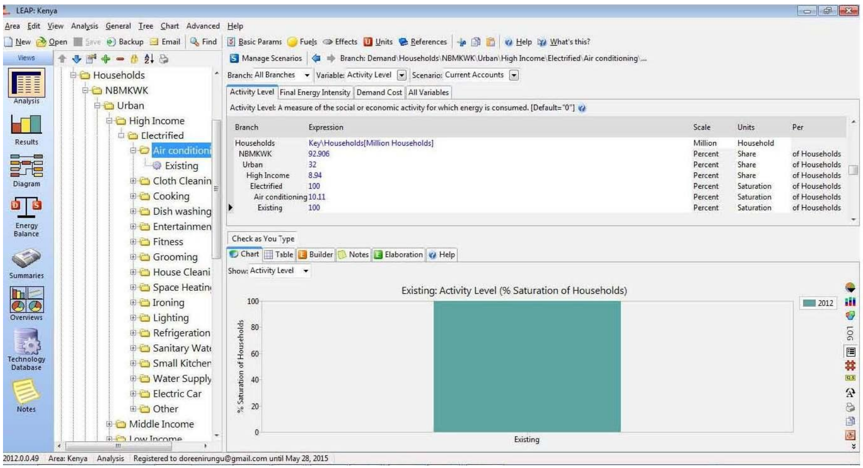


Figure 3: Clustered appliances

The projections were done by increasing the number of consumers connected in the various regions, using the annual growth rates given in the load forecast report and by increasing the penetration of the appliances with their specific consumptions. Street lighting base year demand was obtained from the Kenya Power (2012) report. The projections were done using number of poles, specific consumption (kWh/pole). Commercial and Industrial base year demand was obtained from the Kenya Power (2012) report. The projections were done using an elasticity factor obtained by relating the power consumption growth rate for the year 2009 to 2011, to the GDP of the respective years obtained from the Kenya Economic Survey Report (KNBS, 2012). This elasticity was then used with the projected GDP to forecast the demand up to the year 2030.

4.2 Transformation Analysis

To connect the demand side to supply, the transmission and distribution losses were taken into account. Losses for the base year were taken as 14.5% which reduces to 14% in 2015 and planning reserve margin of 25% (ERC, 2011). A constant load factor of 68% was used, the load data for base year was also entered as per Figure 4 and 5.

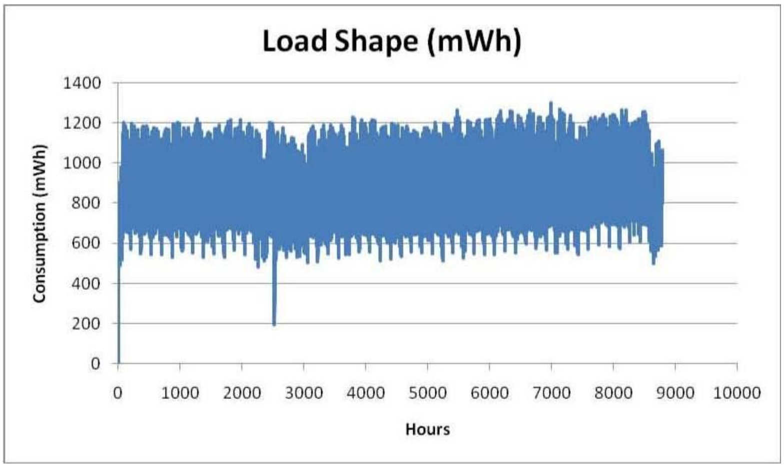


Figure 4: 2012 Load shape

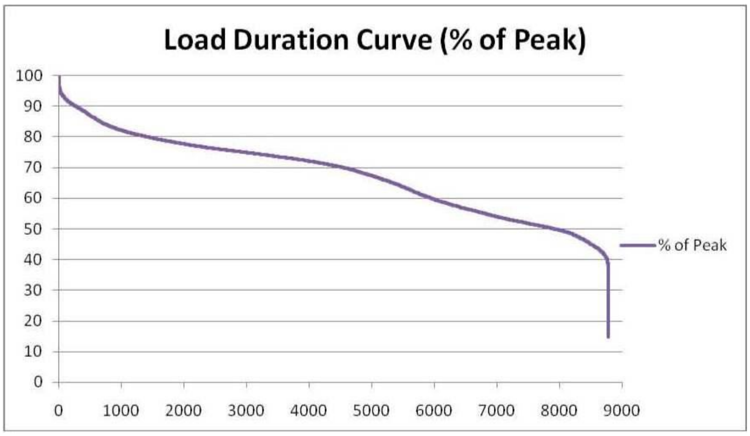


Figure 5: Load duration curve as a (% of peak)

The supply sector was modeled using various technology categories including; hydroelectric turbines, open cycle gas turbine and closed cycle gas turbines, geothermal, coal, biomass, solar PV and wind turbines. For each technology type the capacity, capacity factor, efficiency, maximum availability, merit order(1 for base load plants and 2 for peak load plants), dispatch rule(Merit order rule or run on full capacity rule for the non-dispatchable plants) and first simulation year are specified (Kenya Power, 2012; KenGen, 2012). New additions capacity are added exogenously or endogenously. Exogenous capacity representing the planned additions with specific quantity and type, these were the committed plants in the least cost plan with specific time frames. Endogenous capacity representing the additions of specific technologies that were built on a need basis to meet the electricity consumption requirements as specified by the demand sectors (Heap, 2010).

4.3 Environmental Analysis

The GHG emissions were estimated using the emission factors based on the values recommended by the Intergovernmental panel on Climate Change (IPCC) guidelines for national Greenhouse Gases inventories Tier 1 (IPCC, 2006). The Technology and Environment Database (TED) contained in the LEAP system, was used to link each technology and corresponding quantity of fuel used in electricity generation to average the GHG emissions.

5.0 Results

5.1 Demand Forecast

The analysis, indicates that the demand for power increases from 6340GWh in 2012 to 38,600GWh in 2030 as shown in Figure: 6. This demand will be from the industrial and commercial sectors as the country strives to achieve the middle income status as well as the domestic sector where the connectivity of household is expected to be 100% by 2030 with an increase in electricity use per household both in the urban and rural areas brought about by economic prosperity and material affluence.

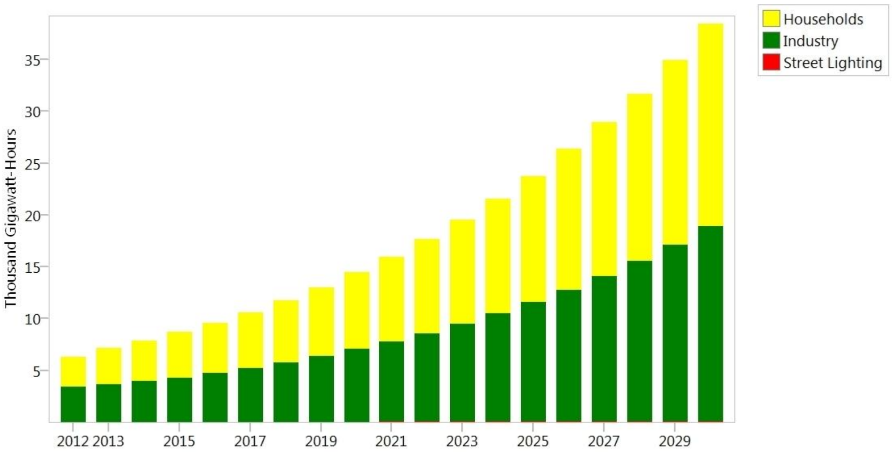


Figure 6: Electricity demand as modeled from 2012-2030

5.2 Power Generation

In the generation sector, the dominance of the hydro power plants will be replaced by geothermal plants whose share increases from 12.9% to 26% in the Reference and renewable scenarios as shown in Table:3. The potential for geothermal in the Rift Valley is estimated to be 10,000MW, while only 209MW has been developed so far (Kenya Power, 2012). The contribution of the MSD plants will reduce fom 29.8% in 2012 to 12.1% in 2030 for reference scenario and 5.9% in the natural gas and renewable scenarios. As geothermal and nuclear power take on the baseload, the contribution of MSD plants will be restricted to Peak loads only.

Table 3: Composition of electricity generation: Base Year and 2030

Technology	2012	Reference	Natural Gas	Renewable
Hydro	49.5%	9.9%	10.0%	10.0%
Geothermal MSD	12.9%	26%	31.8%	26.4%
Plants Gas Plants	29.8%	12.1%	5.9%	5.9%
Cogeneration	3.8%	7.1%	7.1%	7.2%
Imports	1.7%	0%	0%	0%
Coal	0.0%	7.8%	7.9%	8.0%
Nuclear	0.0%	12.0%	12.1%	12.1%
Small Renewables	0.0%	19.6%	19.8%	19.9%
	1.1%	0.2%	0.2%	5.2%
Total	100%	100%	100%	100%

Hence it is expected that power consumers will be cushioned from the fluctuating oil prices which they pay dearly when the MSD plants run as base load to reduce on the load shedding. The share of natural gas plants is set to increase from 3.8% in 2012 to 7.1% in 2030 as the country embraces cleaner technologies of power production. The natural gas will initially be imported from neighbouring countries as Kenya continues to carry out her exploration. The share of power imports is expected to grow to 7.8% in 2030 as the East AFrican Power Pool is actualised. Coal power plants are expected to contribute 12% to the generation capacity. The coal will initially be imported; eventually local coal is expected to be used. Nuclear power is set to come into the mix in 2021 and form 19% of the generation capacity. The small renewables including; small hydro, biomass, and solar PV are also expected to contribute 5.2% in the renewable scenario to enhance exploitation of the natural resources, diversification of generation capacity and promotion of energy security. The contribution of the various technologies to the total power output from 2012 to 2030 is shown in the Figure 7, 8 and 9. For all the scenarios the contribution of natural gas and MSD plants is not captured separately because they run as peak power plants hence the overall power production is minimal as compared to the baseload plants. For the renewable scenario the small hydro contribution is captured as the plants will run on full capacity without being dispatched.

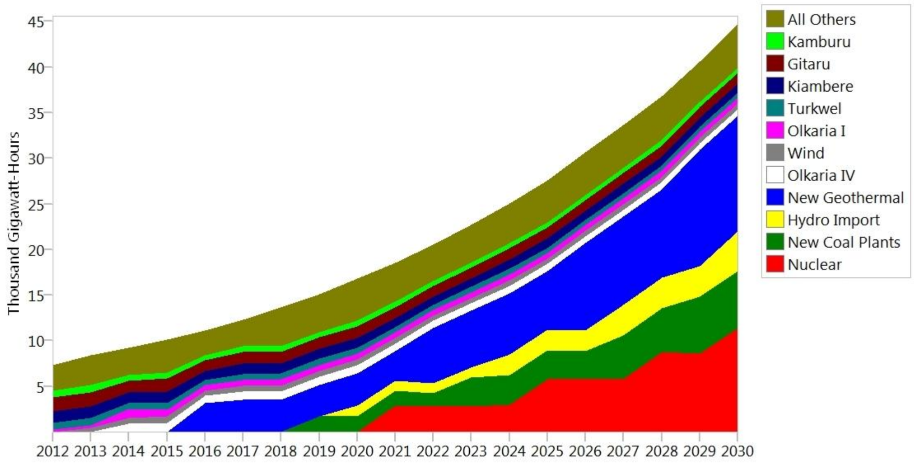


Figure 7: Power Output: Reference Scenario

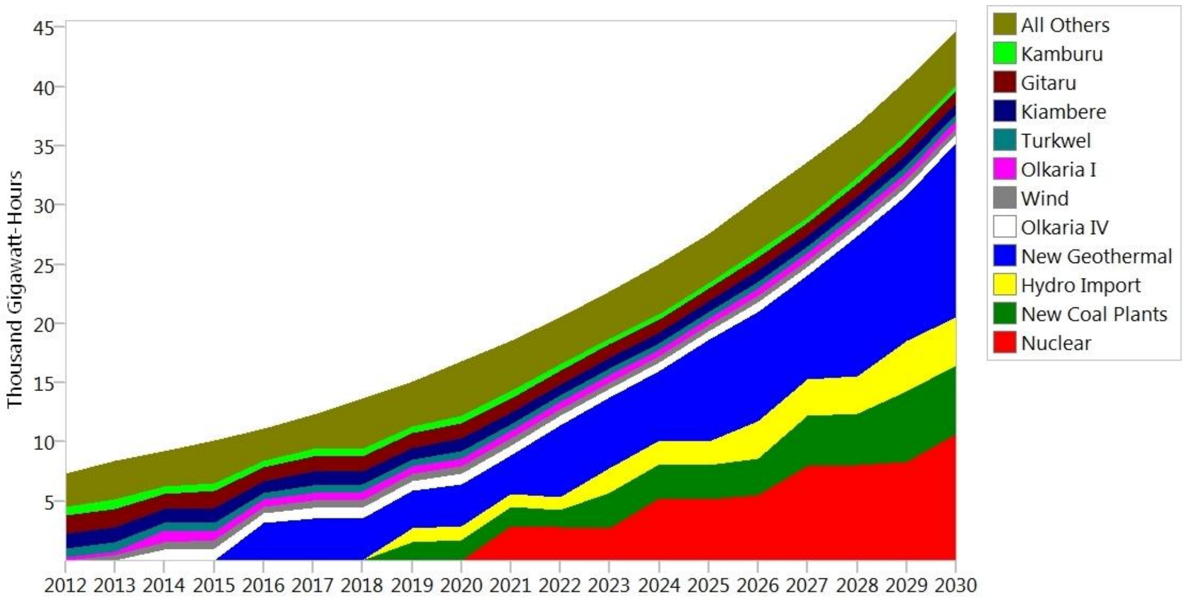


Figure 8: Power Output: natural gas scenario

5.3 Emission Analysis

The renewable scenario has the lowest emission levels as shown in Figure: 10, therefore forms the most sustainable scenario. It is noted that as the power consumption and production increase, the emissions also increase.

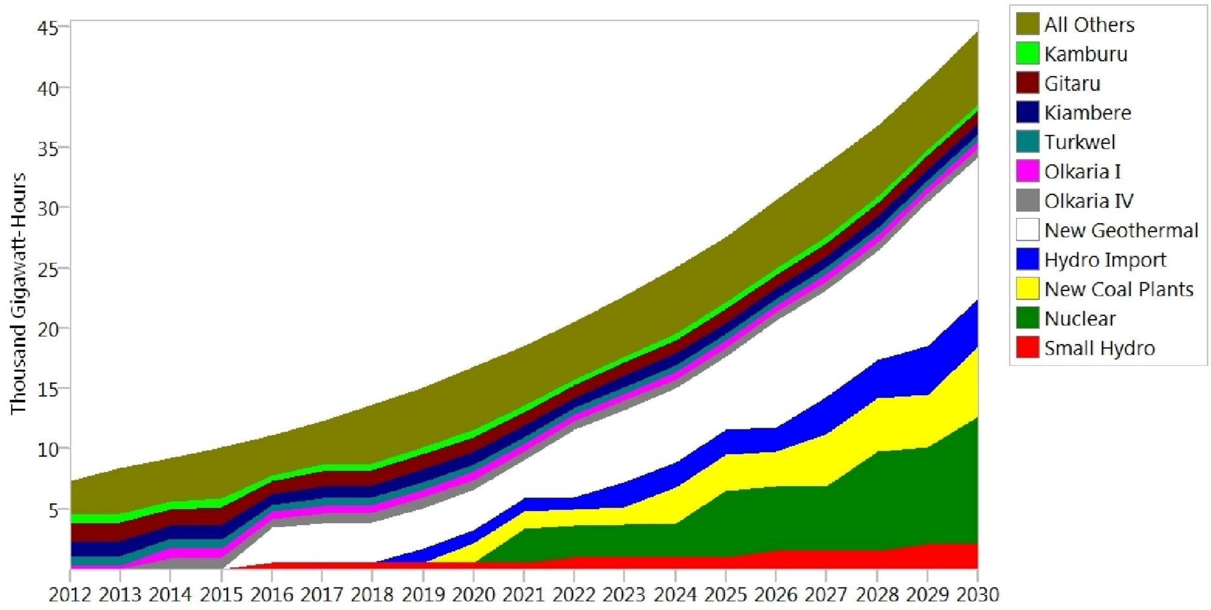


Figure 9: Power Output: Renewable Scenario

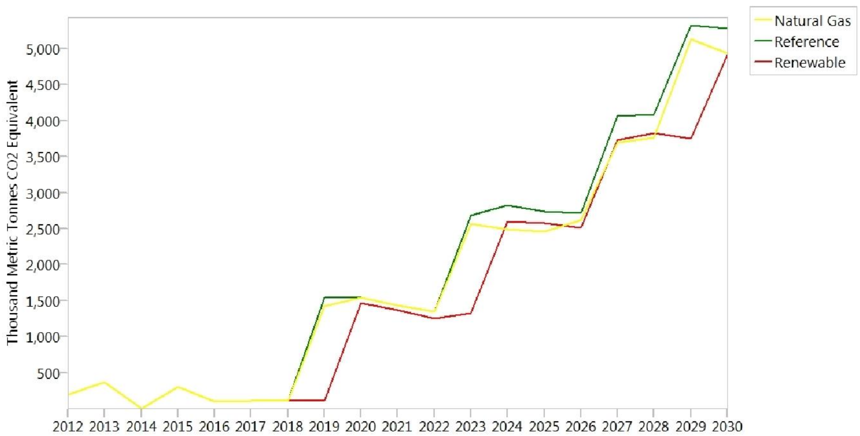


Figure 10: Emission comparison for the scenarios

5.4 Cost Analysis

Cost analysis indicates that the reference scenario is the most ideal. Table: 4 show the costs for the candidate plants used. The net present value of the natural gas scenario over and above that of the reference scenario is $100.2million discounted at 8% and using the 2012 U.S. Dollar, while that of the renewable scenario comes to $53.1million. The cost implication for every tonne of GHG saved is $45.6/tCO$_2$Eq for the natural gas scenario and $8.6/tCO$_2$Eq the renewable scenario.

Table 4: Cost of technologies used as candidates for the expansion plan

Technology	Overnight Costs ($2012/kW)	Fixed Costs ($2012/kW)	Variable costs($2012/kWh)
MSD Plants (160MW)	1232	56.4	0.008
Geothermal Plants (140MW)	3296	50.6	0.0050
Nuclear Plant (1000MW)	3661	81.3	0.0044
Coal Plant (300MW)	1900	62.3	0.0039
Gas Turbine (Natural Gas 180MW)	677	10.7	0.01084
Import (1000MW)	411	27.1	0.045
Mutonga (60MW)	3895	19.2	0.0048
LG Falls (140MW)	3270	17.9	0.0048
Wind (300MW)	2077	25.4	0.00090
Small Hydro (1-10MW)	2500	53	0
Biomass (1-10MW)	2000	58	0.009
Solar PV (1-10MW)	2500	34	0

ERC (2011); ECA (2012)

6.0 Conclusion

The research indicates that the renewable scenario is the most suitable and sustainable path for Kenya. The reference scenario which is the Government's least cost power development plan, is confirmed to be the most ideal in terms of costs but has the most emissions as compared to the natural gas and renewable scenario. If the renewable scenario were to be implemented, GHG savings of 6.2Million tonnes CO_2eq would be achieved with the enhancement of energy security and at a cost of $ 8.6/t CO_2eq. These costs if compared to the costs of dealing with calamities of climate change like flooding and drought which have been experienced in Kenya, are much less and there is a probability of cost recovery from emission trading. It is recommended that the renewable scenario be implemented.

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